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Urea kinetic analysis of automated peritoneal dialysis allows calculation of a CAPD-equivalent Kt/V_{urea}

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Urea kinetic analysis of automated peritoneal dialysis allows calculation of a CAPD-equivalent Kt/V_{urea}.

Background. Based on evidence of increased mortality with decreasing urea clearance, the Dialysis Outcomes Quality Initiative (DOQI) recommended a weekly Kt/V_{urea} of 2.0 or higher for patients receiving continuous ambulatory peritoneal dialysis (CAPD). DOQI recommendations for automated peritoneal dialysis (APD) are based on efforts to determine the clearance providing urea mass removal equivalent to CAPD. We have adapted a variable volume direct quantitation urea kinetic model (UKM) in an effort to assess DOQI APD guidelines.

Methods. The daily urea mass removed with a weekly Kt/V_{urea} of 2.0 was calculated using standardized CAPD patient profiles. Using this value and defining the pre-APD plasma urea nitrogen (PUN) as C_0 and equal to the CAPD steady-state PUN, the UKM reiteratively calculated the urea clearance from an APD treatment that provided a urea mass removal equivalent to CAPD. A total weekly Kt/V_{urea} was calculated for various levels of continuous urea clearance (defined as $K_{pr}t/V_{urea}$) and plotted against $K_{pr}t/V_{urea}$ (weekly). The impact of dialytic time (t), drain volume of the daytime dwell (δ), and ultrafiltration volume (ϕ) were assessed, and all profiles were performed with C_0 equal to the corresponding blood urea nitrogen of 60, 70, and 80 mg/dL.

Results. The relationship between requisite weekly Kt/V_{urea} and $K_{pr}t/V_{urea}$ (weekly) was linear. Weekly Kt/V_{urea} declined with increasing $K_{pr}t/V_{urea}$, t, δ, and ϕ. The effect of ϕ on the weekly Kt/V_{urea} was independent of $K_{pr}t/V_{urea}$, and the magnitude of the effect of t and δ on the weekly Kt/V_{urea} decreased with increasing continuous clearance. Weekly Kt/V_{urea} values were independent of V and C_0. The latter observation allowed extrapolation of CAPD clearance and urea generation relationships to APD: CAPD-equivalent weekly $Kt/V_{urea} = [700 \times (U_D + U_r)]/(C_0 \times V)$, where U_D and U_r are the daily urea mass (mg) in dialysate and urine, respectively.

Conclusions. The APD urea clearance, which provides urea mass removal equivalent to CAPD, varies as a function of a combination of patient and treatment variables. However, a CAPD-equivalent weekly Kt/V_{urea} can be calculated by collecting appropriate dialysis and urine samples and estimating patient V. The results can be evaluated in the context of evidence-based CAPD guidelines, increasing the precision of adjustment and monitoring of the APD prescription.

Peritoneal dialysis offers patients requiring renal replacement therapy enhanced flexibility and autonomy compared with hemodialysis. In particular, in efforts to accommodate work or school schedules [1, 2], many patients prefer one of the automated peritoneal dialysis (APD) techniques: nightly intermittent peritoneal dialysis (NIPD), APD without a daytime dwell, or continuous cycling peritoneal dialysis (CCPD), APD with a daytime dwell. In addition, APD may reduce the risk of peritonitis compared with continuous ambulatory peritoneal dialysis (CAPD) [3], and given flexibility of dwell volume and time, APD prescriptions can be easily modified at reduced cost [4].

However, adequacy of APD has not been defined precisely. Based on several studies correlating urea clearance and mortality [5–8], the Dialysis Outcomes Quality Initiative (DOQI) recommended measuring peritoneal dialysis adequacy with urea kinetics and established a weekly Kt/V_{urea} goal of at least 2.0 for patients receiving CAPD [9]. Using calculations attempting to determine the clearance necessary to achieve the same urea removal as CAPD, DOQI suggested a weekly Kt/V_{urea} for NIPD and CCPD of 2.2 and 2.1, respectively [9].

The increased risk of mortality with decreasing urea clearance noted in CAPD patients [5–8] stresses the necessity of defining minimum urea clearance parameters in APD. However, APD urea clearance recommendations set too high may make achieving clearance goals difficult for certain patients, particularly large persons and low transporters [10], leading to reconsideration of

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what may otherwise be their optimal dialysis modality. Thus, based on the concept that with the same normalized protein catabolic rate (nPCR), the APD dose producing identical urea mass removal to CAPD will provide comparable outcomes, we have modified a variable volume direct quantitation urea kinetic model (UKM) to assess DOQI recommendations for APD weekly Kt/V_{urea}.

In this study, using standardized patient profiles, the UKM was used to calculate the APD urea clearance necessary to achieve urea mass removal identical to CAPD with a weekly Kt/V_{urea} of 2.0. The results indicate that the necessary APD clearance depends on the treatment time, ultrafiltration volume, clearance from the daytime dwell, and residual renal urea clearance. Most importantly, the results validate extrapolation of the CAPD relationship between urea generation and clearance to stable patients receiving APD, thus allowing a clinically practical calculation of a CAPD-equivalent weekly Kt/V_{urea}.

METHODS

Data reported are patterned on the DOQI estimates of the dose of hemodialysis necessary to equate to a CAPD weekly Kt/V_{urea} of 2.0 for patients with various levels of continuous urea clearance [9]. For APD, continuous urea clearance (K_{pr}) equals the sum of residual renal function (K_r) and the daytime dwell (K_p). Data were generated by first calculating the daily urea mass (U_{CAPD}) removed from standardized CAPD patients with a stable nPCR, steady-state plasma urea nitrogen (PUN), volume of urea distribution (V), and weekly Kt/V_{urea} of 2.0. Based on the assumptions that the concentration of urea in peritoneal fluid immediately prior to APD initiation was equal to PUN [11] and that 500 mL of the daytime dwell were absorbed, the urea mass removed by K_p was calculated and subtracted from U_{CAPD}. Using the UKM, urea clearance from the APD treatment (K_{APD}) was then calculated for identical patients undergoing NIPD or CCPD.

These calculations used the underlying assumption of CAPD, that the level of continuous clearance from CAPD that is clinically equivalent to intermittent therapies (hemodialysis or APD), is that clearance resulting in a CAPD steady-state PUN equal to the predialysis PUN of the intermittent therapy with the same nPCR [12–14]. Thus, for all patient profiles, pre-APD PUN was set equal to the CAPD steady-state PUN used to calculate U_{CAPD}. For each NIPD patient profile, K_{APD} was calculated for K_{pr} corresponding to a weekly $K_{pr}t/V_{urea}$ of 0, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, and 1.75. For CCPD, since $K_{pr} = 0$ was impossible, K_{APD} calculations were made instead for the K_{pr} corresponding to the weekly $K_{pr}t/V_{urea}$ seen when $K_r = 0$ and for weekly $K_{pr}t/V_{urea}$ equal to 0.50, 0.75, 1.00, 1.25, 1.50, and 1.75. The total clearance necessary to achieve urea mass removal equal to U_{CAPD} was then calculated as follows:

$$Kt/V_{urea}\ (\text{weekly}) = (K_{APD}t/V) \times 7 + K_{pr}t/V_{urea}\ (\text{weekly}) \quad \text{(Eq. 1)}$$

Kt/V_{urea} (weekly) was then plotted against $K_{pr}t/V_{urea}$ (weekly). The impact on weekly Kt/V_{urea} of V, dialytic time, clearance from the daytime dwell, and ultrafiltration volume was assessed using patient profiles changing one variable and holding the others constant. All profiles were performed using a predialysis PUN equal to the corresponding blood urea nitrogen (BUN) of 60, 70, and 80 mg/dL.

Definition of variables and related formulae

t,θ	APD dialytic period, interdialytic period, in minutes ($t + \theta = 1440$ min).
C_0,C_1,C_2	Pre-, post-, and next treatment pre-APD PUN, in mg/mL ($C_0 = C_2$). PUN values were corrected for protein and lipid volume and units converted from mg/dL to mg/mL by dividing BUN by 93.
C_{CAPD}	CAPD steady-state PUN ($C_{CAPD} = C_0$).
V	Volume of urea distribution, in mL.
δ	Drain volume of the daytime dwell, assuming 500 mL absorbed, in mL (δ = daytime dwell − 500).
ϕ	Ultrafiltration volume, in mL.
K_{APD}	Urea clearance from APD, mL/min.
K_p	Daytime dwell urea clearance, corrected to 24 hours, in mL/min ($K_p = \delta/1440$).
K_{pr}	Continuous daily non-APD urea clearance, in mL/min ($K_{pr} = K_p + K_r$).
ξ	Weekly $K_{pr}t/V_{urea}$.
K_r	Residual renal urea clearance, in mL/min [$K_r = K_{pr} - K_p = (\xi \cdot V)/(7 \cdot 1440) - (\delta/1440)$].
B	Rate of dialytic volume loss, in mL/min ($B = -\phi/t$).
β	Rate of interdialytic weight gain, in mL/min. To consider its impact on urea removal from K_r, the volume of the daytime dwell drained was considered an increase in distribution volume during the interdialytic period. Hence, $\beta = (\phi + \delta)/\theta$.
U_D	Daily urea mass removed by the APD treatment and the daytime dwell combined, in mg.
U_r	Daily urea mass removed by residual renal function, in mg.
U	Daily urea mass removed, in mg ($U_D + U_r = U = U_{CAPD}$). For CAPD, if weekly $Kt/V = 2$, and $U_{CAPD} = K \cdot t \cdot C_{CAPD}$, then daily $U_{CAPD} = 2 \cdot V \cdot C_{CAPD}/7$.
G	Daily urea generation rate, in mg/min ($G = U_{CAPD}/1440$).

UKM mathematical program

All variables are defined or can be directly calculated except C_1 and K_{APD}. These values are calculated by solving, through reiteration, four equations defined by modeling the urea kinetics in standardized APD patients. Calculations are performed using the software program *Mathcad PLUS 6.0*, from Mathsoft, Inc. (Cambridge, MA, USA).

$$K_t = K_{APD} + K_r \quad \text{(Eq. 2)}$$

$$C_1 = G/(K_t + B) + [C_0 - G/(K_t + B)] \cdot (1 + B \cdot t/V)^{-(1 + Kt/B)} \quad \text{(Eq. 3)}$$

$$C_0 = G/(K_r + \beta) + [C_1 - G/(K_r + \beta)] \cdot (1 + \beta \cdot \theta/V + B \cdot t)^{-(1 + Kr/\beta)} \quad \text{(Eq. 4)}$$

$$U_{CAPD} - \delta \cdot C_0 = K_t \cdot G \cdot t/(K_t + B) + V \cdot [C_0 - G/(K_t + B)] \cdot [1 - (1 + B \cdot t/V)^{-(Kt/B)}] + K_r \cdot G \cdot \theta/(K_r + \beta) + (V + B \cdot t) \cdot [C_1 - G/(K_r + \beta)] \cdot [1 - (1 + \beta \cdot \theta/V + B \cdot t)^{-(Kr/\beta)}] \quad \text{(Eq. 5)}$$

Equations 3 and 4 are the solutions during the dialytic and interdialytic interval, respectively, for the single-pool, variable-volume differential equation that describes in vivo urea kinetics:

$$d(V \cdot C)/dt = G - K_t \cdot C \quad \text{(Eq. 6)}$$

Equation 5 equates the daily urea mass removed by CAPD (with a weekly Kt/V_{urea} of 2.0) minus the urea cleared from the daytime dwell to the sum of the urea removed by the APD treatment and residual renal clearance for both the dialytic and the interdialytic time intervals. This solution is derived from a differential equation that describes ex vivo urea removal:

$$dU/dt = k \cdot C \quad \text{(Eq. 7)}$$

where C is described by equations 3 or 4, depending on the time period of interest. During the dialytic interval, for APD and renal urea removal, then $k = K_t$; for APD urea removal only, then $k = K_{APD}$. During the interdialytic interval, $k = K_r$. This solves to the following:

$$U = K_t \cdot G \cdot t/(K_t + B) + V \cdot (k/K_t) \cdot [C_0 - G/(K_t + B)] \cdot [1 - (1 + B \cdot t/V)^{-(Kt/B)}] \quad \text{(Eq. 8)}$$

$$U = K_r \cdot G \cdot \theta/(K_r + \beta) + (V + B \cdot t) \cdot [C_1 - G/(K_r + \beta)] \cdot [1 - (1 + \beta \cdot \theta/V + B \cdot t)^{-(Kr/\beta)}] \quad \text{(Eq. 9)}$$

for the dialytic and interdialytic periods, respectively.

Calculation of APD clearance using standard methods: Comparison to the UKM

DOQI recommends that APD adequacy be estimated by measuring the urea concentration in the pooled dialysate and drawing an interdialytic midpoint PUN to calculate urea clearance, assuming a linear interdialytic urea concentration curve. For each patient profile, the urea mass removed by the APD treatment (U_{APD}) and the pre-APD PUN values (C_0, C_2) were defined, and the post-APD PUN (C_1) was generated by the UKM. To verify the linearity of the interdialytic interval and suitability of the interdialytic midpoint PUN concept to our model, the mean interdialytic urea concentration [$C_m = (C_1 + C_2)/2$] was determined, and an APD treatment clearance was calculated (K_m) using standard methods:

$$K_m \text{ (mL/min)} = U_{APD}/C_m \cdot t \quad \text{(Eq. 10)}$$

Verification of the suitability of our UKM to the standard method using the interdialytic midpoint PUN was achieved by calculating the ratio K_{APD}/K_m and determining its proximity to unity.

RESULTS

Comparison of the UKM to standard methods

For all patient profiles generated, K_{APD}/K_m ranged from 1.000 to 1.004 (data not shown).

Kt/V_{urea} (weekly) vs. $K_{pr}t/V_{urea}$ (weekly)

The relationship between the APD weekly Kt/V_{urea} necessary to achieve urea mass removal equivalent to CAPD with a weekly Kt/V_{urea} equal to 2.0 and $K_{pr}t/V_{urea}$ (weekly) was inversely linear (Figs. 1–3).

Variation in pre-APD BUN

When V, t, ϕ, and δ were held constant, weekly Kt/V_{urea} values were independent of pre-APD BUN values. The lines generated for pre-APD BUN of 60, 70, and 80 mg/dL were identical (data not shown).

Variation in volume of distribution

With treatment duration set at 600 minutes, the line defined by a V, δ, and ϕ of 50 L, 2000 mL, and 3000 mL, respectively, was identical to the line with all patient/treatment parameters reduced by 50% (V, δ, and ϕ of 25 L, 1000 mL, and 1500 mL, respectively). Thus, weekly Kt/V_{urea} was independent of V.

Variation in ultrafiltration volume

These profiles held V, t, and δ constant at 50 L, 600 minutes, and 2000 mL, respectively (Fig. 1). For NIPD, increasing ultrafiltration volumes of 1000, 2000, and 3000 mL meant that when K_r equaled zero, the weekly Kt/V_{urea} needed to achieve urea mass removal equivalent

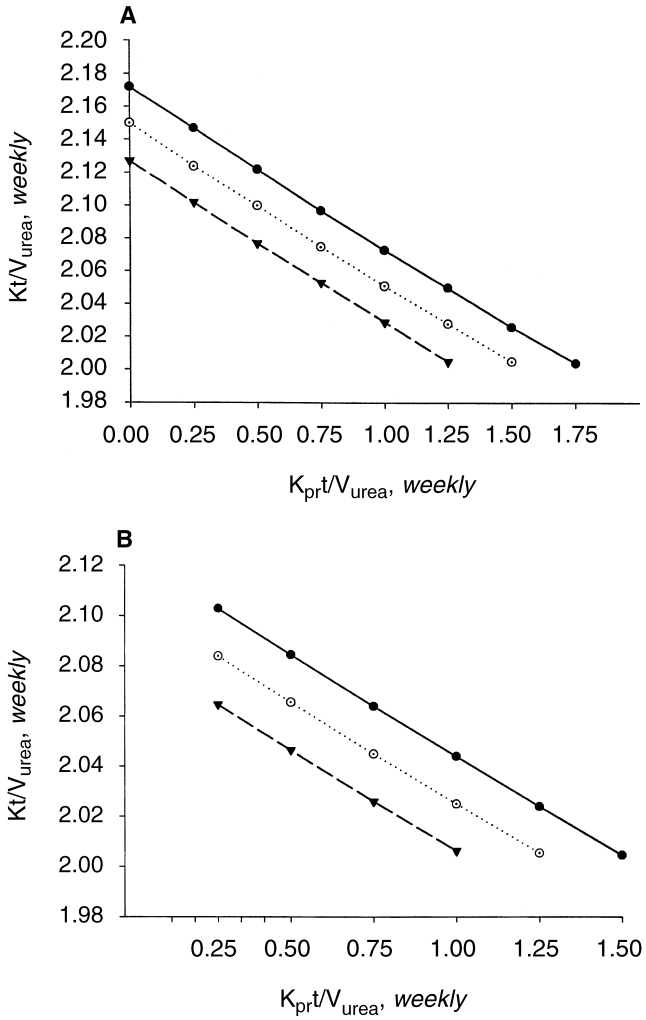

Fig. 1. Variation in ultrafiltration volume. Definitions include: V, patient volume of urea distribution; δ, volume of the daytime dwell drained; ϕ, ultrafiltration volume; t, dialytic time. The Kt/V_{urea} (weekly) necessary to provide urea mass removal equal to the same patient receiving CAPD and a Kt/V_{urea} (weekly) of 2.0 is seen for (*A*) nightly intermittent peritoneal dialysis (NIPD) and (*B*) continuous cycling peritoneal dialysis (CCPD). Twenty milliliters of ultrafiltration per liter of distribution volume decreases the Kt/V_{urea} (weekly) approximately 0.02 for NIPD and CCPD. This relationship is independent of the decrease in Kt/V_{urea} (weekly) with increasing continuous clearance ($K_{pr}t/V_{urea}$), such that lines altering the ultrafiltration volume in the same patient are parallel. Symbols in A are: (●) V = 50 L, ϕ = 1000 mL, t = 600 min; (⊙) V = 50 L, ϕ = 2000 mL, t = 600 min; (▼) V = 50 L, ϕ = 3000 mL, t = 600 min. Symbols in B are: (●) V = 50 L, ϕ = 1000 mL, δ = 2000 mL, t = 600 min; (⊙) V = 50 L, ϕ = 2000 mL, δ = 2000 mL, t = 600 min; (▼) V = 50 L, ϕ = 3000 mL, δ = 2000 mL, t = 600 min.

to CAPD with a weekly Kt/V_{urea} of 2.0 decreased to 2.170, 2.147, and 2.124, respectively. The weekly Kt/V_{urea} decreased as the proportion of ultrafiltration volume to V increases, such that 20 mL of ultrafiltration per liter of V lowered the weekly Kt/V_{urea} by 0.023. For CCPD, increasing ultrafiltration volumes of 1000, 2000, and 3000 mL meant that when K_r equaled zero, the weekly Kt/V_{urea} needed to achieve urea mass removal equivalent to CAPD with a

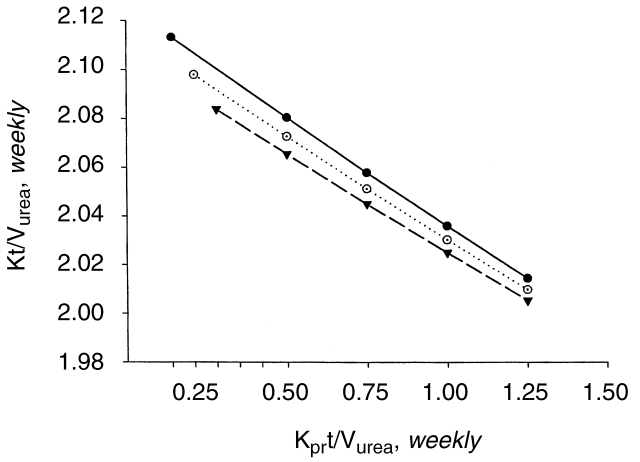

Fig. 2. Variation in daytime dwell volume. Definitions are: V, patient volume of urea distribution; δ, volume of the daytime dwell drained; ϕ, ultrafiltration volume; t, dialytic time. The Kt/V_{urea} (weekly) necessary to provide urea mass removal equal to the same patient receiving CAPD and a Kt/V_{urea} (weekly) of 2.0 decreases with increasing daytime dwell volume. The magnitude of this reduction is dependent on the proportion of the daytime dwell volume to distribution volume and decreases to a small degree with increasing continuous clearance ($K_{pr}t/V_{urea}$), such that the lines gradually converge. Symbols are: (●) V = 50 L, ϕ = 2000 mL, δ = 1000 mL, t = 600 min; (⊙) V = 50 L, ϕ = 2000 mL, δ = 1500 mL, t = 600 min; (▼) V = 50 L, ϕ = 2000 mL, δ = 2000 mL, t = 600 min.

weekly Kt/V_{urea} of 2.0 decreased to 2.103, 2.084, and 2.065, respectively. The weekly Kt/V_{urea} decreased as the proportion of ultrafiltration volume to V increased, such that 20 mL of ultrafiltration per liter of V lowered the weekly Kt/V_{urea} by 0.019. For both NIPD and CCPD, the effect of ultrafiltration on the weekly Kt/V_{urea} was unchanged with increasing $K_{pr}t/V_{urea}$, such that the lines described in Figure 1 were parallel.

Variation in daytime dwell volume

These profiles held V, t, and ϕ constant at 50 L, 600 minutes, and 2000 mL, respectively (Fig. 2). The impact of the daytime dwell on urea clearance needed to achieve urea mass removal equivalent to CAPD was dependent on the volume of dialysate drained after the prolonged dwell. Assuming 500 mL fluid reabsorption, CCPD with increasing drain volumes of the daytime dwell of 1000, 1500, and 2000 mL (meaning initial daytime dwell volumes of 1500, 2000, and 2500 mL) meant that when K_r equaled zero, the weekly Kt/V_{urea} needed to achieve urea mass removal equivalent to CAPD with a weekly Kt/V_{urea} of 2.0 decreased to 2.113, 2.098, and 2.084, respectively. The magnitude of this reduction in weekly Kt/V_{urea} is dependent on the proportion of δ to V and decreases to a small degree with increasing $K_{pr}t/V_{urea}$, such that the lines described in Figure 2 slowly converge with increasing continuous clearance.

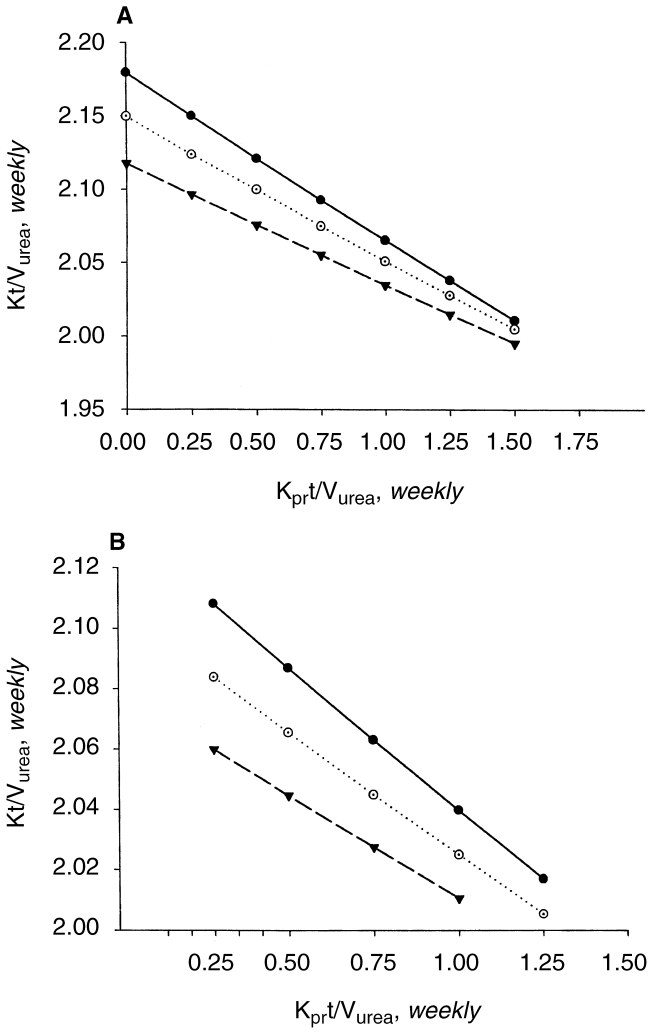

Fig. 3. Variation in dialytic time. Definitions are: V, patient volume of urea distribution; δ, volume of the daytime dwell drained; ϕ, ultrafiltration volume; t, dialytic time. The Kt/V_{urea} (weekly) necessary to provide urea mass removal equal to the same patient receiving CAPD and a Kt/V_{urea} (weekly) of 2.0 decreases with increasing dialytic time. The magnitude of these differences narrows with increasing continuous clearance ($K_{pr}t/V_{urea}$). Symbols in (*A*) are: (●) V = 50 L, ϕ = 2000 mL, t = 480 min; (⊙) V = 50 L, ϕ = 2000 mL, t = 600 min; (▼) V = 50 L, ϕ = 2000 mL, t = 720 min. Symbols in (*B*) are: (●) V = 50 L, ϕ = 2000 mL, δ = 2000 mL, t = 480 min; (⊙) V = 50 L, ϕ = 2000 mL, δ = 2000 mL, t = 600 min; (▼) V = 50 L, ϕ = 2000 mL, δ = 2000 mL, t = 720 min.

Variation in dialytic time

These profiles held V, δ, and ϕ constant at 50 L, 2000 mL, and 2000 mL, respectively (Fig. 3). For NIPD, increasing dialytic times of 480, 600, and 720 minutes meant that when K_r equaled zero, the weekly Kt/V_{urea} needed to achieve urea mass removal equivalent to CAPD with a weekly Kt/V_{urea} of 2.0 decreased to 2.177, 2.147, and 2.118, respectively. For CCPD, increasing dialytic times of 480, 600, and 720 minutes meant that when K_r equals zero, the weekly Kt/V_{urea} needed to achieve urea mass removal equivalent to CAPD with a weekly Kt/V_{urea} of 2.0 decreased to 2.108, 2.084, and 2.060, respectively. The magnitude of these differences in weekly Kt/V_{urea} narrowed with increasing $K_{pr}t/V_{urea}$, such that the lines described in Figure 3 converge with increasing continuous clearance.

DISCUSSION

Urea kinetic models based on the measurement of urea mass removed have been proposed as the most accurate methods to quantitate hemodialysis [15, 16]. Drawbacks have included the need to collect and quantitate a large volume of spent dialysate and requirement of an equilibrated postdialysis BUN for single-pool models to account for urea rebound and compartment effects. In addition, direct quantitation models generally assume a fixed volume of urea distribution [15]. We have found that application of our program to APD addresses these problems. The volume of dialysate in peritoneal dialysis is amenable to quantitation. Although BUN does fall during the APD treatment, solute shifts are slow compared with hemodialysis, and single-compartment kinetics can be assumed. Finally, the UKM allows estimation of the impact of ultrafiltration on clearance, maximizing the precision of this calculation.

In formulating weekly Kt/V_{urea} recommendations for APD, DOQI assumed that treatments that provide equivalent urea mass removal will also provide equivalent patient outcomes [9]. Our strategy has been similar, first estimating the urea mass removed by the daytime dwell, and then calculating the APD treatment clearance necessary to provide urea mass removal equivalent to that derived from CAPD with a weekly Kt/V_{urea} of 2.0. Thus, DOQI's calculations that a NIPD weekly Kt/V_{urea} of 2.16 (with recommended clearance rounded to 2.20) provides equivalent urea mass removal to CAPD with a weekly Kt/V_{urea} of 2.0 [9] are almost identical to our NIPD profile of a patient with ultrafiltration of 1000 mL and no residual renal function (Fig. 1A). In fact, DOQI's guidelines for APD are designed to minimize the risk of patients receiving less dialysis than that which optimizes CAPD patient survival. To that end, our data indicate that the guidelines are successful.

However, further analysis of our data indicate that the necessary APD clearances are generally lower than the DOQI APD guidelines [9] and that the precise clearance necessary depends on treatment and patient variables. For example, increased ultrafiltration and daytime dwell drain volumes will reduce the necessary APD weekly Kt/V_{urea}. The patient profiles indicate that 20 mL of ultrafiltration per liter of distribution volume reduce the necessary weekly Kt/V_{urea} by approximately 0.02. The effect derives from steady-state kinetics, meaning the same predialysis PUN in patients with the same urea genera-

tion, with resultant higher postdialysis PUN in patients with increased volume contraction. The time-averaged PUN is therefore higher, meaning increased urea mass removed from the same residual renal function and reduced urea removal necessary from the APD treatment.

Increasing the daytime dwell volume, or more precisely the volume of dialysate drained prior to the next treatment, is also helpful in reducing the required CCPD dose, especially when residual renal function is minimal. The urea mass removed from a prolonged dwell is dependent on the volume of dialysate drained. Thus, for our patient profiles, we have assumed absorption of a portion of the daytime dwell, but prescriptions that maximize dialysate volume through the daytime period will best reduce the CCPD urea clearance needed to meet goals for urea mass removal. In addition, it is important to analyze the assumption on which the daytime dwell data generated are based, that dialysate and plasma urea concentrations are equal after a 12- to 14-hour dwell. Gotch and Keen report 50% equilibration times of 1.2 and 3.0 hours in average and low transporters, respectively [11]. The dialysate urea concentration after a 12-hour dwell will therefore be 99 and 95% of that in plasma in average and low transporters, respectively. Thus, the daytime dwell data should extrapolate to all but the rare patient with markedly low urea transport.

The effects of ultrafiltration, daytime dwell volume, and treatment time on the necessary APD treatment clearance are small when compared with the impact of residual renal function. Continuous urea clearance as provided by residual renal function is more efficient in removing urea mass than identical clearance from a discontinuous therapy like APD. Thus, as weekly K_rt/V_{urea} increases, the weekly Kt/V_{urea} approaches 2.0.

Unfortunately, since the precise urea clearance necessary for any given patient depends on the combination of residual renal clearance, treatment time, and the proportion of ultrafiltration and daytime dwell volumes to distribution volume, individualized APD weekly Kt/V_{urea} goals are impractical without computer software utilization. However, if equivalent APD and CAPD urea mass removal provides equivalent patient outcomes, calculation of a CAPD-equivalent weekly Kt/V_{urea}, with a goal set at 2.0 regardless of treatment modality, should provide a simpler alternative to achieve dialysis adequacy. In fact, given the equivalence of CAPD and APD when CAPD urea clearance results in a steady-state PUN equal to the pre-APD PUN [12–14], and since the APD clearance needed to achieve urea mass removal equivalent to CAPD is independent of pre-APD PUN, extrapolation to APD of equations used in CAPD to calculate urea clearance is justified. Substitution of the pre-APD PUN (C_0) value for the CAPD steady-state PUN in these equations allows calculation of a CAPD-equivalent weekly Kt/V_{urea}:

$$U = U_{CAPD} = U_D + U_r \quad \text{(Eq. 11)}$$

$$U_{CAPD} = Kt \cdot C_0 \quad \text{(Eq. 12)}$$

Combining equations [11] and [12] yields,

$$Kt/V_{urea}\ (\text{daily}) = (U_D + U_r)/(C_0 \cdot V) \quad \text{(Eq. 13)}$$

$$Kt/V_{urea}\ (\text{weekly}) = [7 \cdot (U_D + U_r)]/(C_0 \cdot V) \quad \text{(Eq. 14)}$$

If equilibration of urea between plasma and dialysate is complete after a 12 to 14 hour dwell [11], the predialysis PUN (C_0) can be closely approximated by aliquoting a small volume of peritoneal fluid just prior to APD initiation and measuring the urea nitrogen concentration. This measurement will reflect correction for the protein and lipid fractions of plasma, but is generally expressed in units of mg/dL.

$$Kt/V_{urea}(\text{weekly}) = [700 \cdot (U_D + U_r)]/(C_0 \cdot V) \quad \text{(Eq. 15)}$$

Thus, a CAPD-equivalent weekly Kt/V_{urea} for APD can be calculated simply by measuring the urea mass (mg) in a 24-hour specimen of spent dialysate and urine, measuring the urea nitrogen concentration in the peritoneal fluid immediately prior to APD initiation (mg/dL), and estimating the patient urea volume of distribution (mL) using the methods of Watson, Watson, and Batt [17] or Hume and Weyers [18].

For the rare patient in whom plasma and dialysate urea concentration has not equilibrated after 12 to 14 hours or in individuals whose dialysis prescription includes a daytime drain or dialysate exchange, a pre-APD plasma urea measurement is required to calculate the CAPD-equivalent weekly Kt/V. Although inconvenient, this method may be preferable, since in these patients the interdialytic urea concentration curve is nonlinear and estimates based on a midpoint PUN would be imprecise.

Furthermore, the CAPD-equivalent weekly Kt/V is related to the pre-APD PUN and nPCR by an equation described by Gotch [19]:

$$nPCR = C_0 \cdot [Kt/V_{urea}\ (\text{weekly})]/188.17 + 0.17 \quad \text{(Eq. 16)}$$

Combining equations 15 and 16 allows the derivation of an equation for nPCR, which is dependent solely on the urea mass removed from dialysis and residual renal function:

$$nPCR = 3.72 \cdot (U_D + U_r)/V + 0.17 \quad \text{(Eq. 17)}$$

Advantages of these calculations include elimination of the need for blood sampling and the potential difficulties obtaining the interdialytic midpoint BUN. In fact, data from these standardized patient profiles confirm that results of the standard method recommended by

DOQI [9] are essentially identical to those obtained with this UKM when the midpoint BUN is drawn precisely. Thus, rigorous testing and confirmation of the clinical applicability of the CAPD-equivalent Kt/V_{urea} and nPCR equations will allow estimations of APD adequacy, which can be directly compared with CAPD outcome studies [5–8], facilitating the precision of adjustment and long-term monitoring of the APD prescription.

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